

CORRECTION OF SAGITTAL IMBALANCE

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In recent years, much progress has been made in the assessment of sagittal imbalance, both before and after surgical correction. Part of this progress can be attributed to the fact that the position of the pelvis (veritable "pelvic vertebra" according to Dubousset) and that of the lower limbs are now taken into account. We shall describe the most precise technique of measuring sagittal imbalance, how to prevent it during posterior spinal surgery and, lastly, the various types of surgical correction, notably osteotomies and their indications.

EVALUATION OF SAGITTAL BALANCE

Sagittal balance is no longer evaluated using only the angles of cervical lordosis, thoracic kyphosis and lumbar lordosis. Many years ago, Delmas distinguished dynamic morphotypes, i.e. patients with marked angles of kyphosis and lordosis, from static morphotypes, in

which these curves are flatter. During [1] convincingly demonstrated that the position of the pelvis in anteversion or retroversion influences lumbar and thoracic curves.

The more the pelvis is in anteversion, the more horizontal is the sacrum, the lower and more anterior tilts the superior sacral endplate and the more accentuated is lumbar lordosis. On the contrary, when the pelvis is in retroversion, the sacrum is more upright, the superior sacral endplate is more horizontal and lumbar lordosis is smaller. Using barycentrometry, Duval-Beaupère [2] described angles that characterize the form of the pelvis, its position and that of the trunk. Pelvic incidence is a morphological angle the value of which stops changing at the end of growth. Its average value is 51°. If this angle is greater, the subject's spinal curves are more marked (dynamic type). The pelvic tilt is an angle characterizing the position of the sacrum and its average value is 12° if the incidence is 51°. The pelvic-tilt increases in case of retroversion of the pelvis,

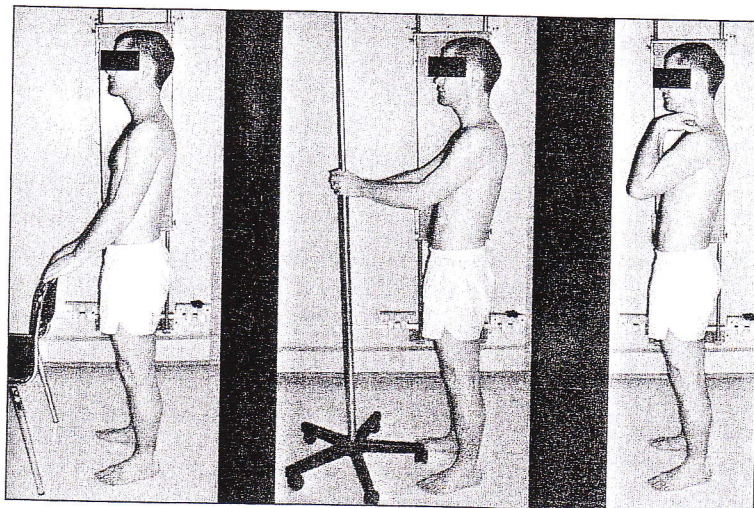
which is a very classic mechanism for the compensation of anterior imbalance, because retroversion positions the femoral heads (FHs) more anteriorly, closer to vertical alignment with the external auditory canals (EACs).

The sagittal list at T9 is the angle between a plumb line and a line from this vertebra, the center of mass of the trunk in barycentrometry, to the FHs. The average sagittal list at T9 is 11° and can decrease, or even have negative values in case of severe anterior imbalance. Itoi [3] stressed the importance of the position of the knees, which will bend only in severe cases of anterior imbalance: a femorotibial angle will then appear and place the trunk in a more posterior position.

The overall balance of the trunk can be evaluated by determining the position of a vertical line through the center of the C7 vertebral body (C7 plumb line) with respect to the anterior or posterior corner of the sacral endplate. To have a more encompassing picture of the vertebral column including the cervical column, one may draw a vertical line from the EACs. According to Gangnet's

measurements [4], this line passes slightly posterior to the FHs or even through them. The different mechanisms of adaptation to anterior imbalance including retroversion of the pelvis and flexion of the knees are attempts to align the EACs vertical to the FHs. This means that an increase in lumbar lordosis automatically leads to an increase in thoracic kyphosis if the thoracic column is flexible. In severe anterior imbalance (as observed in ankylosing spondylitis, for example) the position of the head can be analyzed in terms of specific angles (angle between the nose-chin line and a vertical line, angle between the direction of vision and a horizontal line, angle between a vertical line and the occipitodorsal line).

The measurement of these angles should be made under very precise conditions: standing for lateral views with the hands resting on the back of a chair, an IV stand at the height of the pubis or, to be more precise, at the height of the clavicles (more reproducible position, even though it hides the cervical region) (fig. 1). To obtain a reproducible position of the cervical



*Fig. 1 :
3 reproducible
positions on
lateral X-ray*

column, subjects can stare into their own pupils in a mirror placed in front of them [5]. It is important to obtain full spine views, including the "cranial and pelvic vertebrae", to localize the EAC and the FHs and to show the position of knees: they should be maintained in extension when the X-ray is made (fig. 2 et 3). More sophisticated means can be used, especially for clinical research: for example, stereoradiography, force platforms, or the EOS system developed by Charpak.

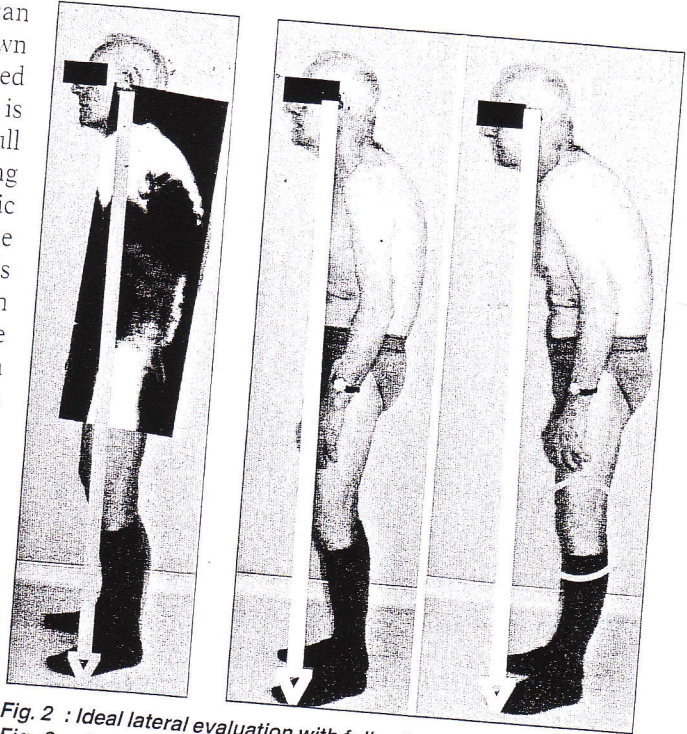
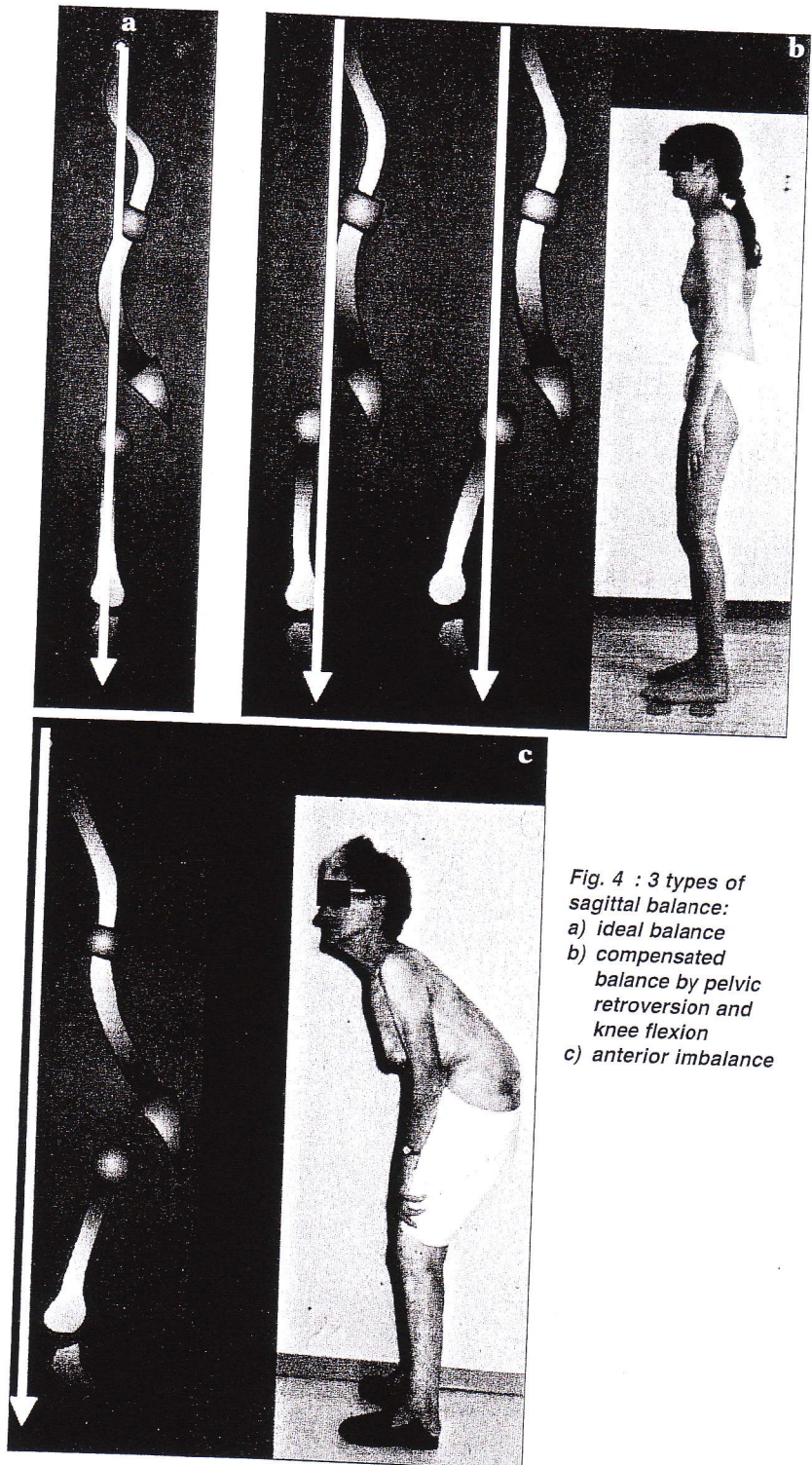


Fig. 2 : Ideal lateral evaluation with full spine and full limbs views.
 Fig. 3 : Sagittal imbalance increased by knee extension.

WHEN THE WORK-UP IS COMPLETE ONE DISTINGUISH 3 OVERALL TYPES OF SAGITTAL BALANCE (fig. 4)

Ideal balance includes, for a given value of incidence, a sagittal list at T9 and pelvic tilt with normal values.

In compensated balance, as in ideal balance, the EACs and FHs lie on the same vertical line, but this is achieved thanks to posterior tilting of the pelvis and, in some cases, flexion of the knees. Finally, in anterior imbalance, in spite of retroversion of the pelvis and flexion of the knees, a vertical line through the EACs lies anterior to the FHs.



*Fig. 4 : 3 types of sagittal balance:
a) ideal balance
b) compensated balance by pelvic retroversion and knee flexion
c) anterior imbalance*

THE SURGICAL MANAGEMENT OF ANTERIOR IMBALANCE INCLUDES PREVENTIVE AND CURATIVE MEASURES

Preventive treatment

The preventive measures consist in avoiding postoperative flat back thanks, first of all, to proper installation of the patient. Installed on 4 pads or a Relton-Hall frame, a patient has less lumbar lordosis than in a standing position. Extensive arthrodesis in this position, especially if it includes S1 or the pelvis, reduces lordosis if there is no attempt to preserve lordosis by osteosynthesis (with rods and, in some cases, cages). This lordosis should be calculated preoperatively by taking into account the value of the pelvic incidence. One should also keep in mind the detrimen-

tal effect of posterior surgical exposure on extensor muscles.

Curative treatment

The surgical curative treatment is based upon osteotomies with numerous different techniques:

- Smith-Petersen's osteotomy (SPO) was initially intended for a single level with posterior closure and consequently anterior opening of the discs. This technique presents vascular risks and has been abandoned.
- Multiple posterior osteotomies (MPO) are based upon the same large wedge resection from one foramen to the other next, but the posterior closure is more harmonious. Mobility of the anterior column is necessary. We advocate use of interbody cages, which improve stability. On the average, each posterior osteotomy increases lumbar lordosis by 8 to 10 degrees (fig. 5).

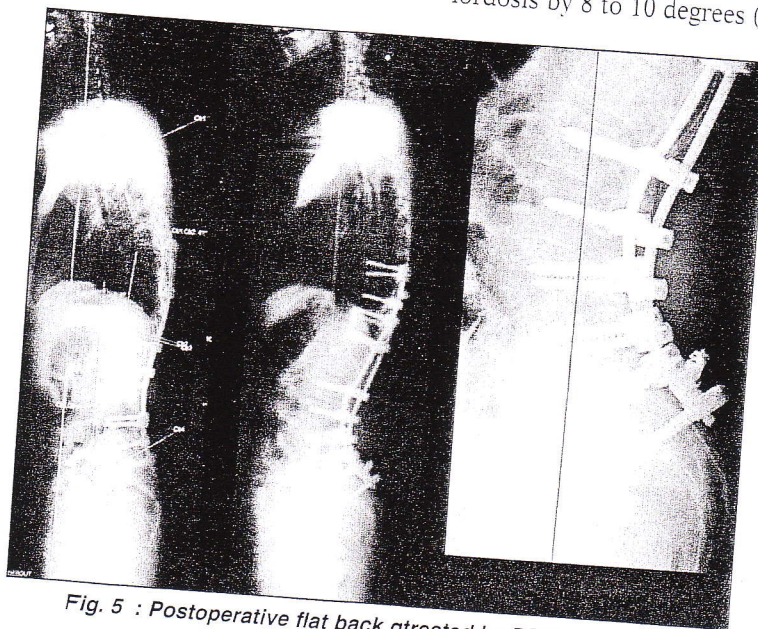


Fig. 5 : Postoperative flat back treated by PSO and cages.

- Pedicle subtraction osteotomy (PSO) is currently the most widely used technique. It consists in removing the posterior arch of the chosen vertebra, both pedicles then a wedge of the vertebral body the posterior base of which is limited by the disc rostrally and the nerve root caudally. If the osteotomy extends to the anterior wall, the maximum angle on a relatively high vertebra is around 40° ; it can attain 45° if the osteotomy stops slightly behind the anterior wall and if there is a small anterior opening in the vertebral body (fig. 6). Preoperative calculation applied using tracings of Xrays or specific software packages is important (fig. 7), because it can simulate different types of correction (variable angles and level of osteotomy). Van Royen [6] showed that the lower the level of osteotomy of a given angle, the more one corrects anterior imbalance. From a technical standpoint, one should insert the implants closest to the osteotomy before performing the osteotomy with an osteotome (angle verification by image intensifier) or with a curette in patients with osteoporosis. Closure is obtained by osteosynthesis with compression

on both sides of the osteotomy and/or by changing the angle of the operating table. The risk of epidural bleeding must be kept in mind and interbody cages should be used adjacent to the osteotomy to reduce the risk of pseudarthrosis (fig. 8 et 9).

- The technique of vertebral resection (eggshell osteotomy) was included in a review by Bridwell [7] of various techniques of osteotomy. It consists in hollowing out one or more vertebral bodies through an anterior approach at the apex of a stiff scoliosis deformity, then in resecting the corresponding neural arches and in correcting with a posterior osteosynthesis. This rarely used technique is intended primarily for rigid deformities in both the sagittal and coronal planes.
- The pelvic osteotomy described by Gérard [8] and more recently by Roussouly [9] is an anterior opening wedge osteotomy similar to Salter's technique that decreases pelvic incidence, verticalizes the sacrum and consequently displaces the trunk anteriorly (fig. 10). This opening can attain 30° and is applicable, in our experience, only to very severe imbalance with no possibility of spinal procedures.

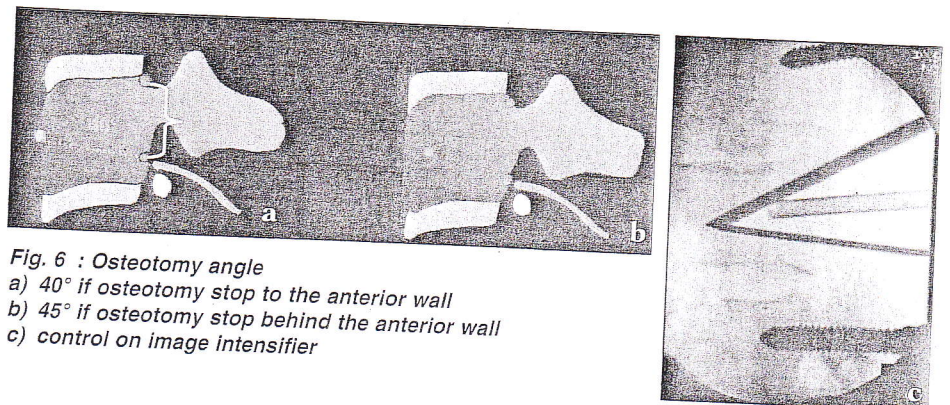


Fig. 6 : Osteotomy angle
 a) 40° if osteotomy stop to the anterior wall
 b) 45° if osteotomy stop behind the anterior wall
 c) control on image intensifier

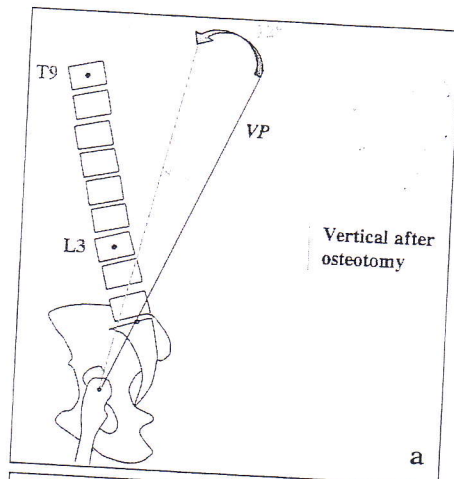


Fig. 7 : Preoperative calculation with specific software

- a) initial position
Vertical after osteotomy
- b) pelvic version correction
Theoric sagittal list
- c) T9 sagittal list correction
Theoric sagittal list to 11°

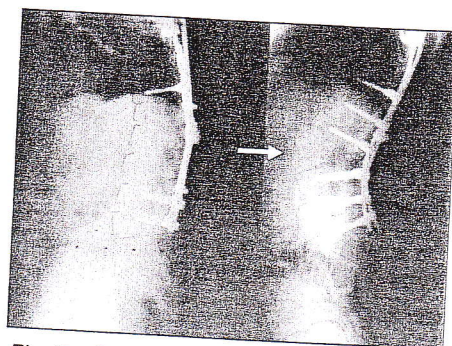
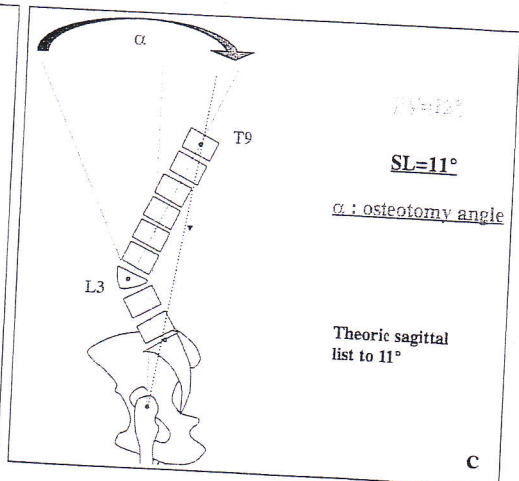
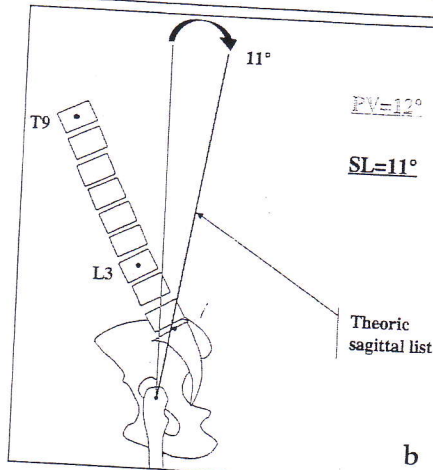


Fig. 8 : Postoperative flat black treated by 40° L3 PSO



Fig. 9 : Postoperative flat black treated by 60° fusioned L2-L3 PSO

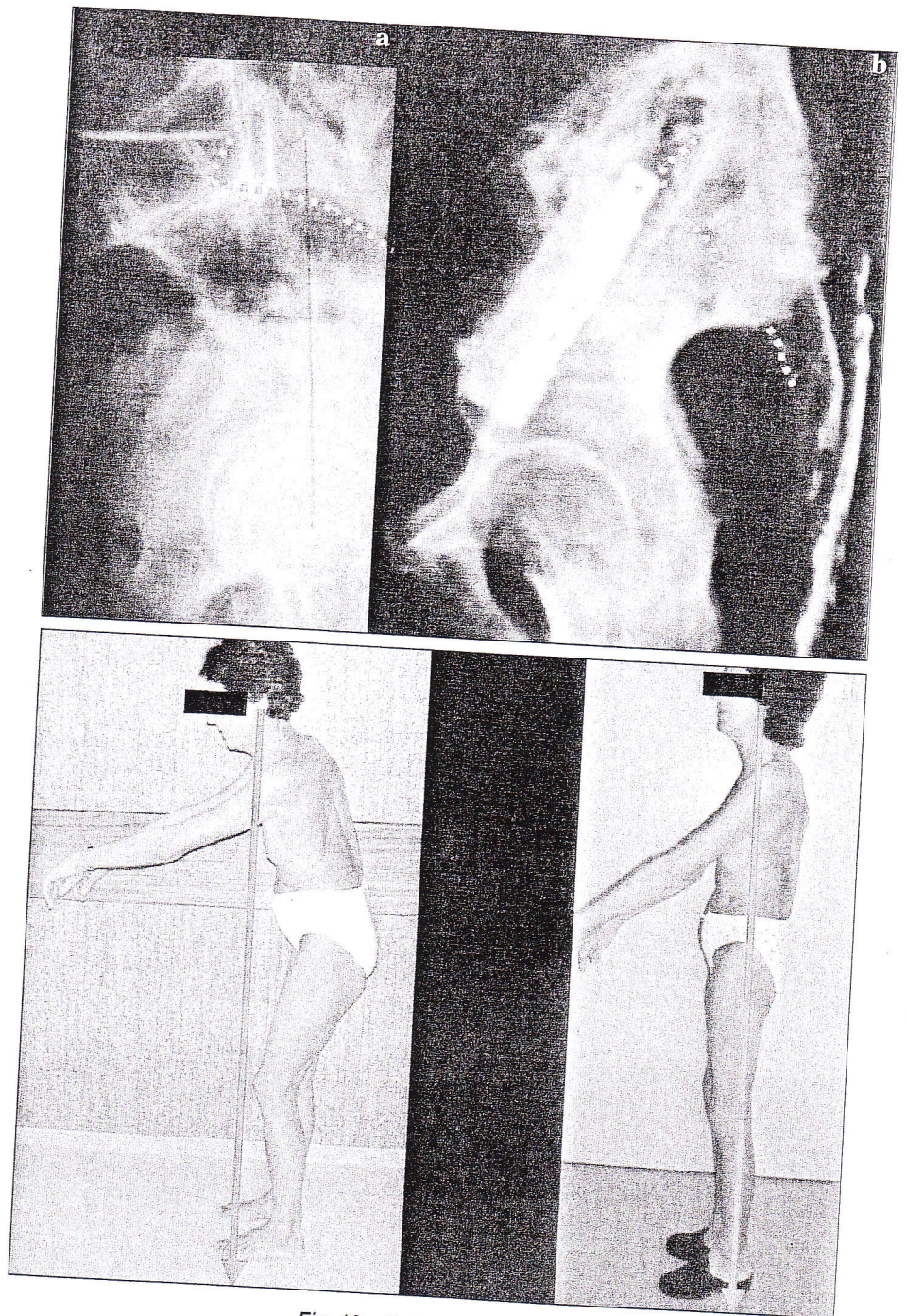


Fig. 10 : Pelvic osteotomy
a) Preop X-ray ; b) postop X-ray
c) preop clinical view ; d) postop clinical view

- Finally, quite recently, sacral subtraction osteotomy (body of S2 and sacral ala has been proposed to correct sagittal imbalance due to callus deformity of the sacrum [10]).

The indications of osteotomies

The indications depend on the topography, the flexible (or stiff) nature of the deformity, and whether it is accompanied by scoliosis.

Transpedicular osteotomy is indicated primarily in purely sagittal deformities involving a stiff column.

Multiple posterior osteotomies are very effective if the anterior column is flexible and they are in most cases reinforced with interbody cages.

Vertebral eggshell resection can be proposed in severe and stiff scoliosis.

Pelvic osteotomy is only exceptionally indicated as a last resort surgical treatment and the same is true, but even moreso, for sacral osteotomy.

THE RESULTS OF OSTEOTOMIES

Radiologically

Radiologically, one may obtain ideal sagittal balance, but often the osteotomy (or osteotomies) leads to compensated balance, notably with retroversion of the pelvis. In certain disorders, such as ankylosing spondylitis, the patient still has anterior imbalance, but with much improvement including a horizontal line of vision, in particular.

Functional status

The functional status is obviously improved with less spinal pain, which often involves a posterior traction phenomenon. Gait has been extensively studied by numerous authors including Lee [11], who reported poorest results in patients who fail to maintain retroversion of the pelvis and who try to compensate severe anterior imbalance by flexion of the knees and paradoxical anteversion of the pelvis. This produces much discomfort with insufficient lordosis in the two posterior rods.

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